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**Evolution on the Shoulders of Giants:
Entrepreneurship and Firm Survival
in the German Laser Industry**

by

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Evolution on the Shoulders of Giants: Entrepreneurship and Firm Survival in the German Laser Industry

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Abstract:

This paper studies 40 years of evolution in the German laser industry to test the generality of evolutionary patterns observed in the U.S. laser industry. Key characteristics found in the U.S. industry are also present in Germany. There is sustained entry into the industry, and neither a shakeout nor first-mover advantages of early entrants are observed. A survival analysis finds that, similar to the U.S. industry, laser firm spin-offs have been systematically more successful than academic startups. Differences in survival and determinants of the spin-off process are traced for alternative kinds of spin-offs, including firms started by serial entrepreneurs.

Keywords: Industry life cycle, submarkets, entrepreneurship, spin-offs, integrating distributors.

JEL classifications: L10, M13, O33.

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1. Introduction

Recent years have seen a surge in research on industrial dynamics, and major contributions have been made to our knowledge on entry, exit, firm growth and survival, as well as innovation. Robust empirical evidence and theoretical accounts have been established for regularities in industry evolution, including the industry life cycle pattern and the occurrence of shakeouts in the number of active firms (Gort and Klepper, 1982; Utterback and Suarez, 1993; Jovanovic and MacDonald, 1994; Klepper, 1996). However, not all industries were found to evolve according to the life cycle pattern and to experience shakeouts, but alternative evolutionary paths exist that involve the specialization of producers (Klepper, 1997). The determinants of these alternative patterns are only beginning to be understood (Klepper and Thompson, 2005). The empirical work on industry evolution has moreover identified systematic differences in the prevalence and performance of entrants with different pre-entry backgrounds, both between diversifying firms and *de novo* entrants, and also among *de novo* entrants whose founders differ in their prior experience. Because of their implications for the viability of new entry, these findings on industry evolution are highly informative for antitrust issues and competition policy. They are also directly relevant for entrepreneurship research and policy.

Much of the existing empirical work has focused on U.S. industries where, due to large domestic markets and a stable institutional environment over the entire 20th century, firm populations tend to be sizable, and consistent time series are comparatively easy to obtain. Less is generally known about industry evolution outside the U.S., and implicitly it is often taken for granted that the regularities observed there generalize to other countries. There is a dearth of direct comparative work juxtaposing evolutionary patterns in identical industries of different countries, particularly as regards contemporary industries. Simons (2001) compares the evolution of the tire and television receiver industries in the U.S. and the U.K., whereas Cantner et al. (2004) analyze the German automobile industry to test whether findings for the U.S. automobile industry (Klepper, 2002a) also apply there. Both studies deal with historical industries that evolved at times when national industries were largely independent and global integration of markets was less pronounced than today.

The present study studies the evolution of the German laser industry from its inception in the early 1960s to the present. The evolution of the U.S. laser industry has already attracted substantial scholarly attention (Sleeper, 1998; Klepper and Sleeper, 2005; Klepper and

Thompson, 2005). It is notable for its deviations from the accepted regularities of industry evolution. In Germany, a laser industry developed more slowly than in the U.S., and German producers faced strong foreign competitors from the beginning. The present study is based on a unique dataset assembled from historical data on all German laser producers. It is set up specifically to facilitate comparisons between the ways the laser industries evolved in Germany and the U.S. In particular, patterns of entry and exit, the origins of entrants into the industry, effects of pre-entry experience on firm performance, and the process of spin-off formation are investigated. The study goes beyond the prior research on the U.S. laser industry in making a finer distinction between types of entrants, including different kinds of spin-off entrants.

Numerous parallels are identified in the evolution of the laser industries in both countries. Similar to the U.S. industry, no shakeout is observed over four decades of industry evolution, entrants with different pre-entry backgrounds differ systematically in their performance, and employee learning emerges as a primary driving force of the spin-off process in the German laser industry. These findings indicate the generality of prior results on the U.S. laser industry and thus help validate the theoretical accounts offered to explain these results. They moreover provide new empirical evidence on the origins, prevalence, and viability of entrepreneurial activities in a German high-technology industry. The study sheds new light on the spin-off process in Germany, as well as on the role of international competitors in the evolution of a national industry.

The paper is structured as follows: Section 2 reviews both the general results on patterns of industry evolution and the divergent findings for the U.S. laser industry. Section 3 discusses the prior work on performance effects of pre-entry experience to derive predictions for the German laser industry. Section 4 describes the data. Results on timing and composition of entry into the German laser industry are presented in section 5. Section 6 reports findings from survival analyses tracing performance differences between different groups of entrants, and section 7 reports results of ordered logit estimations analyzing the determinants of spin-off formation. In section 8, the findings are discussed and concluding remarks offered.

2. Industry evolution in the U.S. laser industry: why no shakeout?

General findings on industry evolution

Empirical work on industry evolution (Gort and Klepper, 1982; Klepper and Graddy, 1990; cf. Klepper, 1997, for a survey) has found that the majority of (narrowly defined) industries evolve according to a life cycle pattern with distinct phases of development. In the initial, “embryonic” stage of the industry, the market is small, product designs are simple, and the further development of the industry is highly uncertain. The number of active firms tends to be large, production processes are based on general purpose machinery, and product innovation figures prominently in competition. The ensuing “growth” stage is characterized by growing market volume, stabilization of the basic design parameters of the product, a slowdown in product innovation, and the use of increasingly specialized machinery. In this stage, a “shakeout” of producers regularly occurs. Existing firms withdraw from the market, whereas the number of new entries decreases, resulting in net exit. Finally, in the “mature” phase of the life cycle, output growth and new entry are expected to decline further, and product innovation becomes less important for competitive success vis-à-vis process innovation and marketing efforts.

Various theoretical explanations for the empirical patterns, in particular the shakeout in the number of producers, have been proposed. Utterback and Suárez (1993) relate the shakeout to the emergence of a dominant product design in the industry. The dominant design increases the profitability of process innovations and induces investment in cost-saving, large-scale production facilities. It reduces the opportunities for new entry, while incumbents unable to adapt to the dominant design are forced to exit. Jovanovic and MacDonald (1994) suggest that the shakeout is caused by an exogenous refinement innovation that increases the minimum efficient scale of firms in the industry and in this way causes net exit. Klepper’s (1996) model of industry evolution is driven by increasing returns of process R&D, as larger firms can spread R&D costs over a larger output base. This mechanism perpetuates firm size differentials: larger initial size translates into lower product price and consequently further growth based on larger demand. Over time, new entry becomes less and less profitable, and the less successful innovators among the industry incumbents are driven from the market, hence the shakeout in the number of producers. All three theories feature technological change as the fundamental driving force of industry evolution.¹ They predict that rates of new entry as well as the number of active firms decrease as the industry matures, and that earlier

¹ In addition to technological factors, herd behavior and informational cascades (Geroski and Mazzucato, 2001; Horvath et al., 2001) have been suggested as driving forces in industry evolution.

(pre-shakeout) entrants on average perform better than later ones. In contrast, the theories strongly differ in their assumptions on the nature of technological change, in particular in their emphasis on singular events versus gradual change (cf. Klepper and Simons, 1997).

The industry life cycle pattern provides a good characterization of the evolution of entry, exit, and the number of active firms in many industries. However, a substantial minority of industries does not exhibit the predicted regularities such as declining entry rates or a shakeout. Instead, in these industries entrants with different capabilities or backgrounds specialize on different activities. Most important for the present discussion is a specialization pattern along product submarkets, which was observed, among others, in the U.S. laser industry (Klepper, 1997).² To account for evolutionary patterns in industries where submarkets figure prominently, Klepper and Thompson (2005) developed a theoretical model based on the stochastic birth and death of submarkets. Firms enter as specialists active in a single submarket, and the average number of submarkets served increases as firms get older. The likelihood of entry into new submarkets is independent of the firm's existing activities, which is consistent with assuming there are no economies of scope between submarkets. Firms exit from a submarket only when the submarket gets destroyed. They exit from the industry altogether when all their submarkets have become destroyed. Consequently, the survival chances of a given firm increase with the number of submarkets the firm is active in. Holding size constant, survival chances moreover increase in firm age.

The evolution of the U.S. laser industry

Lasers are light sources based on stimulated photon emission, which is generated through the “pumping” of energy (light or electricity) through a suitable medium. The technological characteristics of laser light, most importantly spatial and temporal coherence, make lasers useful in a broad spectrum of applications.³ Various kinds of media can be used to generate laser light; including dyes, gases (most importantly CO₂ and helium-neon), and solid crystals doped with small concentrations of specific molecules such as neodymium or chromium. In addition, semiconductor or diode lasers have gained increasing importance in past decades,

² Klepper (1997) discusses two alternatives to the submarket pattern of specialization. The first one (observed, e.g., in petrochemicals, diapers, and zippers) sees late in the industry's development the entry of new firms introducing new production processes, improved equipment, or specialized inputs. In the second pattern (e.g., in diagnostic imaging products and automatic bank teller machines), the initial innovators are technologically specialized firms. They bring the new product to the market, but later lose their competitive edge to incumbents of related markets that are able to leverage superior marketing capabilities.

³ Spatial coherence of laser light means that the divergence of a laser beam with increasing distance from its source increases much more slowly than that of conventional light. Temporal coherence means that a light source emits a regular sinus wave with constant wavelength, amplitude, and phase. The well-defined wavelength, which differs between the different kinds of lasers, allows for generating extremely short and powerful pulses of laser light (Weber, 1998, ch. 5).

partially replacing gas and solid-state lasers in a range of applications. The alternative laser media define broad types of lasers.

The U.S. laser industry is an important case of an industry that evolved according to the submarket pattern, and has been used to evaluate the theoretical model of evolution in submarket industries (Klepper and Thompson, 2005). Submarkets are important in the laser industry because there is no such thing as a general purpose laser. Alternative laser types differ not only in their wavelengths and power ranges, but also in economic dimensions such as production cost, energy efficiency, longevity, and ease of handling. The principal fields of laser application (materials processing, marking systems, measurement, health care, and scientific research) accordingly tend to use different laser types. Likewise, within each individual field, variations in the detailed requirements of particular applications usually dictate the adoption of quite different lasers.

As a consequence of these characteristics of laser technology, the development of new laser applications has been closely linked to the availability of new laser types and models throughout the industry's history. At the same time, useful commercial applications of new laser types were frequently not obvious, but lasers had to be customized to specific uses, which normally required in-depth knowledge of these. Because of the problems encountered in developing practical laser applications, the laser was, in its early years, often described as "a solution in search of a problem." In turn, successful new applications opened up new submarkets and created opportunities for entrants. Given the required knowledge of specific user needs, innovative entrants were often protected from the competition of incumbents. Because lasers tend to be application-specific, and production runs of individual models are typically small, economies of scale and scope have been of limited importance in the laser industry to date.⁴

The first workable laser was presented in 1960 by U.S. physicist Theodore Maiman. Studies of the U.S. laser industry found no shakeout in the number of active laser producers more than 30 years into the industry's history (1961-1994). In spite of substantial rates of exit and consolidation, the number of active producers steadily grew over the entire industry history due to new entry (Klepper and Thompson, 2005).⁵ There is moreover no evidence for first-mover advantages in the U.S. laser industry. Sleeper (1998) found no differences in exit hazards between firm cohorts with different entry dates. Specifically, of the 24 earliest laser

⁴ Mass-produced semiconductor lasers found in CD drives and laser printers are a specialty of the Japanese laser industry; they play virtually no role either in the U.S. or German industries.

⁵ This finding does not rule out that a shakeout will occur at a later stage of the industry's history. Note, however, that in other industries shakeouts are typically observed within much shorter periods of observation.

producers entering before 1965, only two were still active in 1994 (Klepper and Sleeper, 2005). Consistent with the submarket pattern of industry evolution, most producers were limited to a single or a few laser types. The U.S. laser industry also exhibits other patterns predicted by the submarket model. Older firms on average produce more laser types than younger ones, the number of laser types decreases before a firm exits the industry, and firms with broader product spectra are less likely to exit (Klepper and Thompson, 2005).

Implications: expected findings for the German laser industry

The existing research on the U.S. laser industry suggests that its evolution was shaped by technological factors, in particular the continued emergence of new submarkets and the lack of economies of scope between laser types. If the evolution of the U.S. laser industry was indeed technology-driven, its basic characteristics should be shared by laser industries in other countries. The U.S. patterns accordingly provide the baseline of the expected findings in the German laser industry. Specifically, for the subsequent empirical analysis, no shakeout, but an increasing number of active firms – due to newly created submarkets – is predicted. In addition, firms are expected to enter with a narrow product portfolio that they broaden subsequently, and firms producing a larger variety of lasers should have a lower hazard of exiting the laser industry.

We know little about how sensitive evolutionary patterns in industries are to differences in timing, technology, and institutional factors, however. Consequently, encountering the same patterns in Germany as in the U.S. cannot be taken for granted. At least two factors are plausible causes of differences between the national industries. First, the U.S. and the German laser industries substantially differed in the timing of entry and in the roots of firms' technological capabilities. The laser was first invented and marketed in the U.S., with military-sponsored research playing an important role in the head start of U.S. producers. In contrast, the German laser industry was lagging behind – a fact already lamented by contemporary industry observers.⁶ One consequence of this difference was that military contractors were among the prominent early entrants into the U.S. laser industry, whereas they played a much lesser role in Germany. They were conceivably less skilled in finding profitable civilian applications than entrants with different backgrounds would have been, which might be one factor underlying the absence of observed first-mover advantages in the U.S. industry. More generally, the flip side of the German lagging-behind was that some of the most fundamental uncertainties faced by the earliest laser producers had already been

⁶ Cf. contemporary editorial comments in the trade press.

settled when substantial entry occurred in Germany. Both arguments imply that early German laser producers may have fared better than their U.S. counterparts, and would help account for potential first-mover advantages in the German laser industry.

Second, as regards the possibility of sustained entry into the laser industry based on new laser types and applications, there is little reason to expect that German firms had less such opportunities than U.S. laser producers. It is less obvious, however, that they were equally willing and able to pursue these opportunities, given that the German economy in the late 20th century is generally seen as less innovative and entrepreneurial than that of the U.S. Accordingly, a lack of sustained entry by German firms into the laser industry might reflect differences in entrepreneurial attitude, financing constraints, and/or supporting institutions.

The present section has focused on broad patterns of entry, exit, survival, and product portfolio. In addition to these regularities of industry evolution, earlier empirical work on the U.S. laser industry has studied the composition of entrants into the industry as well as their performance as laser producers. In the next section, key results of this work will be presented, which again will be used to derive predictions for the German laser industry.

3. Composition of entry and entrant performance: findings for U.S. laser producers and predictions for Germany

General findings on pre-entry experience and performance

Empirical studies based on data from various industries have shown that the prospects of industry entrants systematically differ according to the entrants' pre-entry experience. The findings indicate that both individual entrepreneurs and preexisting organizations are able to transfer useful knowledge to their new organization or field of activity. Two kinds of entrants have been studied in particular: diversifiers from related industries and spin-offs founded by employees of incumbent firms in the industry.

In a study of the U.S. television receiver industry, Klepper and Simons (2000) show that this industry became dominated by diversifying radio producers. Although they represented a minority of all entrants, no firm without a background in radios ever captured a large market share in TV receivers. Diversifying radio producers on average entered earlier, and had a lower exit hazard, than the average entrant. Thompson (2005) similarly finds strong effects of pre-entry experience on survival in the U.S. shipbuilding industry.

Several studies have found that spin-offs started by ex-employees of industry incumbents were significantly more successful than other *de novo* firms whose founders had

not worked in the respective industry before. An oft-cited example for the prominence of spin-offs is semiconductors, where spin-offs – including Fairchild and Intel – have played a crucial role (Moore and Davis, 2004). Likewise, spin-offs were highly successful in the disk drive (Agarwal et al., 2004), automobile (Klepper, 2002b), and tire industries (Buenstorf and Klepper, 2005).

To account for the superior performance of spin-offs, it has frequently been suggested that they benefit from knowledge their founders accumulated in their previous employment. Garvin (1983) has advanced three conditions favoring successful entry by spin-offs. First, in differentiated industries where market niches are little known and change over time, industry insiders are able to benefit from superior knowledge about customer needs and product opportunities. Second, in the absence of dominant product designs, successful new product types and models are more likely created in an industry. This facilitates spin-off entry, as spin-off founders are often able to draw on R&D activities of their former employers (the spin-offs' "parent firms"). Finally, spin-off entry is favored if crucial capabilities are embodied in skilled labor rather than physical capital or being largely codified. Spin-off formation may moreover be triggered by employee- and firm-specific characteristics and events. Prominent among these are employee frustration stemming from strategy conflicts and rejected ideas, and also mergers, acquisitions, or even exit by the parent firm bringing about changes in management and in employees' career prospects.

Klepper and Sleeper (2005) develop a conceptual model of spin-off entry. Incumbent firms create new knowledge on which new product variants can be based. This knowledge can only be exploited by the firm itself or by an employee spin-off, as it does not spill over beyond the firm's organizational boundaries. Consequently, the incumbent firm can preempt spin-off entry by introducing the new product variant itself. Klepper and Sleeper (2005) argue that for two reasons, not all opportunities of spin-off entry will be preempted. One possibility is that the firm's leadership does not realize the potential of the new product variant. Alternatively, if the hazard of spin-off entry is assessed to be low and if introducing the new variant would cannibalize existing products, the incumbent firm may deliberately choose not to preempt all opportunities for profitable spin-off entry even if recognizing their potential. Agarwal et al. (2004) focus on the ability of incumbent firms to exploit new technological knowledge. They suggest that an incumbent firm's capacity to enter new submarkets depends on both technological and marketing capabilities. Superior capabilities in either dimension enhance the opportunities for employee learning, thus increasing the number of potential spin-offs created in a given incumbent firm. However, the likelihood of actual spin-off generation

is reduced if firms possess equally strong technological and marketing capabilities, allowing them to both generate and successfully exploit new knowledge.

Composition of entry and entrant performance in the U.S. laser industry

Both diversifiers and spin-offs played a prominent role in the U.S. laser industry. Diversifiers accounted for 193 out of 486 (60 %) entrants into the U.S. industry (Klepper and Sleeper, 2005). Sleeper (1998, ch. 8) reports detailed analyses of diversifier performance. Her results indicate that the more closely the background of preexisting firms was related to the laser industry, the better they tended to perform in this industry.

As was related in the previous section, new submarkets were prominent in the laser industry, and industry experience was crucial in identifying profitable laser applications. According to Garvin's (1983) list of industry conditions favorable to spin-off entry, substantial rates of spin-off entry would thus be expected in lasers. Spin-offs (broadly defined to include serial entrepreneurship) indeed contributed substantially to entry into the U.S. laser industry, where they accounted for 16 % of the entrants. Consistent with the conjecture that spin-off founders are able to transfer relevant capabilities from the parent firm to the spin-off, the exit hazard of spin-offs was significantly below that of other entrants. Within the group of spin-offs, firms whose founders had a sales or marketing background performed better than those whose founders had a technical or product development background (Sleeper, 1998, ch. 8). Klepper and Sleeper (2005) provide further empirical evidence indicating the role of learning in the spin-off process. They show that spin-offs tended to produce similar lasers as their parent firms. Moreover, the likelihood that a firm spawned a spin-off producing a particular laser type depended on the firm's specific experience in that type rather than its general experience in lasers. More successful laser firms were more likely to spawn spin-offs, indicating that there was more valuable knowledge to gain in better performing firms. Finally, being acquired by another firm systematically increased a laser firm's likelihood of having spin-offs, which is consistent with the argument that spin-off formation is favored by triggering events.

Expected patterns in the German laser industry

Prior to the world's first laser in 1960, there is no evidence of substantial laser research in Germany. However, when learning about the U.S. developments, German university and industry researchers quickly initiated efforts toward constructing lasers themselves. Historical evidence indicates that constructing a workable laser was within the reach of skilled industry

physicists and engineers (Albrecht, 1996). Accordingly, in addition to entry based on the commercial application of university research, existing German firms with various kinds of backgrounds were able to diversify into the laser industry based on in-house technological developments. Diversifiers are therefore expected to figure prominently among entrants into the German laser industry from its beginnings.

The evolution of the German laser industry has moreover been heavily affected by public research. The first dedicated laser research institutes were established in the 1970s. In the 1980s and 1990s, a number of new institutes and research centers were set up to concentrate on laser applications and technology transfer from the academic to the commercial sector (Heilmann, 2003). Collaboration between public research and commercial laser producers was instrumental for important product innovations by established German laser firms, for example in the field of lasers for material processing (Hügel, 2003). Public research moreover continued to create opportunities for new entrants. Industry-level developments were reinforced by economy-wide trends. Over the past decades, the organization of new firms out of university labs and other public research institutions has increasingly been emphasized as an important avenue for the commercial application of scientific knowledge in Germany. Academic startups have accordingly enjoyed growing political support and public attention, and a substantial and increasing share of entrants into the German laser industry can be expected to have an academic background. It is more difficult to predict the performance of academic start-ups. Based on the theoretical considerations and empirical findings on the performance of entrants in the U.S., it can be speculated that academic startups were disadvantaged by a lack of knowledge about customer needs and promising product innovations. It is *a priori* unclear whether the technological capabilities of academic startups were sufficient to compensate for these shortcomings.

Finally, the prominent role and superior performance of spin-offs in the U.S. laser industry has already been noted. If the industry characteristics outlined by Garvin (1983) are indeed the primary determinants of opportunities for spin-off entry, there should have been plenty of room for spin-offs in the German laser industry. We would therefore expect spin-offs to account for a similar share of total entry into the U.S. and in Germany. Moreover, if spin-off founders benefited from learning about technologies and customer needs while working for industry incumbents, then similarities between the products of spin-offs and their parent firms are to be expected, and more successful incumbents should have generated more spin-offs. Information on the survival of parent firms and the types of lasers produced by parents and their spin-offs can be used to test these conjectures.

Little is known, however, about the role of spin-offs in the German economy. Accordingly, it cannot be taken for granted that opportunities for spin-off entry were actually exploited. Wagner (2004) finds that employees of young and small firms are particularly likely to start new firms. Since his study uses cross-sectional data on individual entrepreneurs rather than data on the firm population of a single industry, the results are not directly comparable to the research on spin-offs done in the context of industry evolution. Specifically, they cannot be used to evaluate the quantitative significance of spin-offs in Germany. Differences in the importance of spin-offs in Germany, as compared to the U.S., may have had to do with institutional and cultural factors. Given the traditionally strong role of long-term employment spells, lifetime careers within the same company, and perceptions of employee loyalty, it is plausible to expect that laser spin-offs played a lesser role in Germany than in the U.S. Finding that triggering events such as parent firm acquisition or exit were more important in the German spin-off process would indirectly support this conjecture.

As regards spin-off performance, there is again little prior research on German firms to draw upon except for the general finding by Brüderl et al. (1992), based on a broad sample of Bavarian entrepreneurs, that firms whose founders had prior industry experience had significantly higher survival chances than firms whose founders were new to the industry. This result is consistent with theoretical arguments stressing the role of learning by spin-off founders, and also with findings for the U.S. laser industry. The available evidence thus leads us to predict that spin-offs were among the more successful entrants into the German laser industry. In addition, more experienced and better parent firms provide more opportunities for employee learning, and the employees' position conditions their ability to absorb useful knowledge in the parent firm. Spin-off entry and performance is therefore expected to vary with the experience and performance of the parent firm, as well as the spin-off founder's position in the parent firm.

4. Data

Studying the evolution of industries requires the construction of original datasets. Industry classifications in official statistics are generally too broad to reflect the regularities of the industry life cycle, and they provide no information on the product types manufactured by individual producers. In addition, firm-level information is not normally disclosed for the

entire firm population because of privacy considerations, and the anonymity of the data prevents the identification of firm backgrounds.

The present study is based on a comprehensive data collection effort to obtain the following information on all German producers of laser sources from its beginnings through 2003:

- firm's name and location,
- years of entry into and exit from the laser industry,
- type(s) of laser produced initially and over the period of laser production activities, where a distinction is made between seven laser types: solid-state, semiconductor, dye, CO₂, helium-neon, ion, and excimer; as well as a catch-all category of other/unspecified types,⁷
- mergers and acquisitions,
- founders' names and backgrounds, particularly prior employment spells with other laser firms (for *de novo* firms), and
- background of firm prior to entry into laser industry (for diversifying firms).

For the U.S. laser industry, the trade magazine *Laser Focus World* has published a buyers' guide from 1961 to date. It contains most of the above information and provides the principal data source for the existing studies of the U.S. laser industry. In Germany, no analogous source existed prior to 1987 when the trade journal *Optronics* published a buyers' guide, which appeared only once, however. Regularly appearing buyers' guides have been available from 1990 onward; they are produced annually as *Europäischer Laser-Markt* by the trade magazine *Laser*. These guides are used here as the primary data source for the more recent past of the industry. Complementary information from two additional sources is used to identify laser producers in the years before 1987: exhibitor listings of the biannual *Laser* trade fair in Munich, which was first held in 1973; and classified listings of laboratory needs suppliers in the membership journal of the German Physics Association, *Physikalische Blätter* (recently renamed *Physik-Journal*). The earliest entries for laser producers in this publication date from 1964.

The above sources helped identify laser producers as well as their active years in the industry. The information thus obtained could not be used immediately, however, since for three reasons it contained a substantial number of false positives. First, in the listings for the

⁷ This classification corresponds to that adopted in Klepper and Sleeper (2005) with the exception of helium-cadmium lasers, which did not play a substantial role in the German laser industry. For some firms and years, only activities in an aggregate category of gas lasers were reported in the available sources. Using this aggregate category instead of the separate listings for CO₂ and helium-neon, lasers did not change results in the subsequent statistical analyses.

industry's early years, laser manufacturers are not distinguished from distributor firms and importers that did not engage in any manufacturing activities of their own. A number of laser producers moreover acted as distributing agents for other producers, in particular for foreign firms. No listing shows what types of lasers these firms actually produced themselves, and what types they merely distributed. Second, in some cases there is no straightforward way to tell whether a firm was only a laser system producer (using OEM laser sources supplied by another firm) or whether it actually manufactured lasers. Finally, some firms included in the buyers' guides were implausible as laser producers. For example, a handful of firms are, for several years, listed as job shops, which is consistent with other information available on them, yet in a single year they are listed as laser producers.

Because of these limitations, a second step of verifying the data obtained from the primary sources was necessary to identify actual laser producers. To this purpose, a variety of secondary sources were consulted. Extensive use was made of all published volumes of the trade journal *Laser und Optoelektronik* (which has been published under different names continuously from 1969 to the present) and of the more recent *EuroLaser*. Additional information was obtained from the *Hoppenstedt* register of German firms. Furthermore, for firms that are still active, the World Wide Web provided useful information. Based on the additional information, all firms listed in the primary sources were classified into various categories of plausibility ranging from confirmed producers to firms that were explicitly characterized as non-producers in the secondary material. For some 70 potential laser producers, the published material was insufficient to establish their status with a satisfactory degree of certainty. These firms were contacted by e-mail, telephone, or personal contact during the 2005 *Laser* trade fair. For firms that are no longer in existence, information by industry experts and/or former employees could often be obtained. Due to extensive efforts to track firms and individuals, sufficient information could eventually be gathered to classify all but 15 firms listed in the primary sources.⁸ The final sample contains 143 confirmed German producers of laser sources between 1964 and 2003.

Beyond identifying laser producers, the backgrounds of the firm (in the case of diversifiers) or its founder(s) (in the case of *de novo* firms, i.e., startups and spin-offs) had to be identified. The sources consulted to verify the status of producer firms were also used for obtaining this information. In addition, patent searches in the *DEPATISNET* patent database

⁸ For the econometric analysis, the 15 unknown firms were dropped from the sample. Most of them were listed only briefly, and no additional evidence on their laser production was found in the written material or in the expert interviews. Eliminating these short-lived firms appeared the most conservative option with regard to the survival analysis. Two firms (Rofin and Zeiss) entered twice into the laser industry, and their spells in the industry were treated as separate entries.

and publication searches in the *INSPEC* database were used to establish the prior employment of firm founders. Again, when the published information was insufficient to classify the firm according to background, efforts were made to directly contact the firms or individuals connected with them.

5. Results I: timing and composition of entry

The German laser industry had a rather unimpressive start (Figure 1). A small number of German firms started laser production in the 1960s and early 1970s, but foreign (largely U.S. and U.K.) producers generally dominated the German laser market during this period. Many of the early German firms in the laser industry were importers of foreign-made lasers rather than (or, in a number of cases, before) actual laser manufacturers. There was a period of more active entry into the laser industry for most of the 1970s, but entry slowed down again at the end of the decade (Figure 1, lower panel). This decrease in entry reflects the disillusionment that followed the initial euphoria surrounding lasers, as this revolutionary new technology was found difficult to put to practical applications. Entry again picked up speed in the mid-1980s when German laser producers became more prominent in the domestic market as well as abroad. Industrial materials processing applications emerged as the stronghold of the German firms. While U.S. producers were struggling with slow sales in those years, German producers of industrial lasers grew quickly, with laser exports increasing almost fourfold between 1980 and 1987 (Basting, 1989). In 1988, German firms accounted for one third of all industrial lasers produced worldwide, and their share subsequently increased further to some 40% (Heilmann, 2003). Moreover, in the 1990s new German laser firms entered the fields of measurement, marking systems, and health care.

Similar to the U.S. industry, no shakeout has occurred in the German laser industry to date, but the number of active firms has increased throughout industry history (Figure 1, upper panel). This is largely due to increasing numbers of new entrants. The composition of entrants has been diverse in terms of pre-entry experience of firms and founders. Over the entire history of the industry (through 2003), 48 of the 143 entrants (34%) were spin-offs organized by former employees of other producers of laser sources. This number is notable in that it suggests that spin-offs were even more important quantitatively in Germany than in the U.S. 45 of the German entrants (31%) were pre-existing firms diversifying into the laser industry. 28 (20%) of the German laser firms had an academic origin, i.e., they were founded by scientists employed in universities and public research institutes and/or by the academic

institutions themselves. 11 entrants (8%) were laser distributors/importers diversifying into the manufacturing stage, seven entrants (5%) were *de novo* startups with other backgrounds, and the background of four firms (3%) could not be established. There are pronounced differences over time in the composition of entrants and active producers. In particular, the number of spin-offs, and to a lesser extent of academic startups, has strongly increased in recent years (Figure 2).

So far, all firms started by former employees of industry incumbents have been classified as spin-offs. The data allow for a finer subdivision, which may be relevant for studying the characteristics and performance of spin-offs, as well as the determinants of their formation. In 10 of the 48 cases of spin-offs, the impetus for the spin-off firm can be traced back to the parent firm's management. These "voluntary" or "parent" spin-offs (Helfat and Lieberman, 2002) again fall into two subcategories. On the one hand, new, independent laser firms were strategically organized by incumbent firms to pursue different laser activities than the parent firm, mostly to focus on demand segments different from the parent firms' core lines of business. Anecdotal evidence suggests that individual "voluntary" spin-offs were at least in part motivated by financial considerations, including the availability of public startup assistance. On the other hand, there are several cases of management buy-outs taking over the existing laser business from industry incumbents that strategically refocused their activities.

Of the other 38 spin-offs, 10 firms were (co-) organized by individuals who had previously founded another laser firm (which is considered the spin-off's parent firm). These individuals, who brought both industry experience and entrepreneurial experience to their new firms, will in the following be referred to as serial entrepreneurs. The remaining 28 were "involuntary" or "entrepreneurial" spin-offs (Helfat and Lieberman, 2002), started by individuals who had been employees, but not founders or owners, of earlier laser firms.⁹ Most of the theoretical work on spin-offs concentrates on this smaller group of firms, and accordingly it seems useful to distinguish them from the other types of spin-offs in the empirical analysis.

On the exit side of the industry, the role of acquisitions is notable, with 17 German laser producers taken over by competitors. It is not *a priori* evident how to interpret acquisitions, but qualitative evidence suggests that a number of successful firms were

⁹ Klepper and Sleeper (2005) adopt a broad definition of spin-offs based on the prior employers of founders and principals. They do not discuss how many, if any, of their spin-offs are "voluntary" or instances of serial entrepreneurship, even though their qualitative discussion suggests that U.S. spin-offs were predominantly of the "entrepreneurial" type. Note that in the German laser industry, even the share of narrowly defined, "entrepreneurial" spin-offs (28 out of 143 or almost 20 % of all entrants) exceeds the 16 % spin-off share found by Klepper and Sleeper for the U.S. industry.

acquired by competitors. Some of the most prominent acquisitions were made by leading foreign laser producers (e.g., Laser-Optronik and Lambda Physik were both acquired by the U.S. firm Coherent). More recently, German laser producers have been active in acquiring competitors. As a consequence, there are now two large groups of industrial laser producers in Germany (Rofin, which acquired Baasel and Dilas; and Trumpf, which acquired Haas).

The individual submarkets for different types of lasers differ in their development. Gas lasers have in numerous applications been replaced by semiconductor and solid-state lasers (Grupp, 2000; Heilmann, 2003). Specifically, semiconductor lasers have often substituted helium-neon lasers, whereas CO₂ lasers face increasing competition by diode-pumped solid-state (DPSS) lasers, particularly in lower power ranges, and excimer lasers are challenged by tunable solid-state lasers. Given these technological developments, it is not surprising that the numbers of firms active in the markets for semiconductor and solid-state lasers have experienced the strongest growth (Figure 3). In contrast, in the market for helium-neon lasers, and to a lesser extent also in the CO₂, ion and excimer markets, the number of firms has declined.¹⁰ The latter types of lasers have not been substituted entirely, though, which again reflects the variety of submarkets characterizing the industry. At the same time, new types of lasers not distinguished in the traditional classification (in particular, new types of solid-state lasers) have become commercially viable, keeping the total number of laser producers high. At the firm level, the number of submarkets that producers are active in substantially increases with firm age.

6. Results II: firm background and performance

To study whether firms with different characteristics performed differently in the German laser industry, the time period of presence in the laser industry is taken as a measure of firm performance, and the methodology of survival analysis is adopted. Using years of survival in the market as a performance criterion is dictated by the lack of financial data for the complete population of firms in the industry. There are, however, good reasons why longevity is a suitable proxy for performance. Theoretically, the underlying assumption is an opportunity cost argument. If firms that once entered a market leave this market, they may do so either because they are forced to (i.e., they are bankrupt) or because their owners expect to find better ways to invest their capital. Given the irreversibility of some earlier investments, it is

¹⁰ Because of the nature of the data, some of the listings of submarket activities reflect sales rather than production activities.

plausible that voluntary withdrawal from the laser industry indicates substandard performance of the respective firm. It has to be noted that survival in the present context relates only to the firm's activities in the laser industry, and that exit from the laser industry does not imply that the firm has ceased to exist. In addition to exiting from the industry, firms may also disappear from the dataset because they (or their laser activities) are acquired by a competitor. Since the fact of being acquired does not yield systematic information on the performance of the firm, acquisitions by other laser firms are treated as censored exits in the survival analysis.¹¹

Survival analysis models the risk ("hazard") to succumb to some event at time t , conditional on a vector of explanatory variables. The subsequent analysis adopts the parametric Gompertz specification, which assumes that the (unexplained) baseline hazard $h_0(t)$ and the systematic hazard conditional on the vector x_j of independent variables (for subject j) are multiplicatively related

$$h(t | x_j) = h_0(t) \exp(x_j \beta_x),$$

where the baseline hazard $h_0(t)$ is specified as

$$h_0(t) = \exp(\beta_0) \exp(\gamma t).$$

The baseline hazard is thus assumed to increase or decrease exponentially with time. For firm survival, $\gamma < 0$ is expected, i.e., the baseline hazard should decrease with increasing firm age. This prediction reflects a stylized fact of industry dynamics, which posits that exit hazards decrease as firms mature (Dunne et al., 1989). The analyses use annual observations for each year a firm was active in the laser industry, thus allowing for time-varying covariates to be included.

To see whether the lack of first-mover advantages found in the U.S. laser industry is also observed in the German laser industry, performance differences between cohorts of entrants are analyzed first. To this purpose the entrants were divided into three entry cohorts: firms entering before 1985 (26 firms), between 1985 and 1994 (47 firms), and in 1995 or later (70 firms). Given the increase in entry over time, the distinction between cohorts represents a compromise between equal lengths of time intervals and balanced numbers of entrants. The first analysis (reported as Model 1 in Table 1) is a parametric, proportional Gompertz model with dummy variables denoting entrants of the second and third cohorts. As compared to the

¹¹ Firms acquired by non-laser firms remain in the sample and are treated as if they had remained independent.

first cohort (which represents the control group), the 1985-94 entrants have a 25% higher hazard of exit,¹² whereas the hazard of the third cohort is marginally below that of the earliest entrants. Neither difference is significant, nor is the log-likelihood of the model significantly above that of the baseline model. The model thus reproduces the lack of first-mover advantages that characterizes the U.S. laser industry. The coefficient estimate for firm age is positive but not significantly different from zero, suggesting no systematic change in the exit hazard as firms grow older. This result is consistent with Sleeper's (1998) findings on the U.S. laser industry, but it runs counter to the decrease in hazard that is generally found with increasing firm age (Dunne et al., 1989).

Next, a series of models is estimated to identify potential performance effects of firm background. Initially, only a dummy variable indicating the 28 entrants with a background in academic research, i.e., startups founded by scientists or academic institutions, is included in the specification (Model 2 in Table 1). The coefficient estimate of this variable is positive, sizable, and significant (at the .05 level). It suggests that academic startups had more than double the exit hazard of firms in the control group (which consists of all other entrants). The log-likelihood of the specification is significantly (also at the .05 level) above that of the baseline model. These results imply that even in a high-tech industry like lasers, where technology is based on recent scientific research, academic firm founders may be disadvantaged vis-à-vis other entrepreneurs.

In the following specifications, the academic startups and the two small groups of startups organized by non-laser firm employees and of entrants with unknown backgrounds make up the control group. In Model 3, two dummy variables indicate diversifying firms and an aggregate group combining all types of spin-offs, including the integrating distribution firms, which is denoted as *Allspins*. The coefficient estimates of these variables indicate that both the diversifiers and the aggregate spin-off group had exit hazards substantially (40-50 %) below that of the control group. The differences in hazard are significant for both groups (at the .05 and .01 levels, respectively).

The next model takes a closer look at the spin-offs. It distinguishes three types of entrants with direct links to established laser firms: firms organized by serial entrepreneurs who had already started another laser firm before, "entrepreneurial" laser spin-offs started by (non-founder) employees of laser firms, and laser importers/distributors integrating into the manufacturing stage. In addition, a fourth dummy variable denotes diversifiers and "parent"

¹² Hazard ratios are obtained by taking the exponential of the coefficient estimates reported in Table 1.

spin-offs (i.e., strategic divestitures and management buy-outs).¹³ Estimation of this specification (Model 4 in Table 1) obtains very sizable, negative, and almost identical coefficient estimates for the serial entrepreneurs and the integrating diversifiers (both are significant at the .05 level). In contrast, the coefficient estimate for the “entrepreneurial” spin-offs is substantially smaller, and it is not significantly different from zero, indicating that the average performance of these entrants cannot be distinguished statistically from that of the firms in the control group.

A final model specification is estimated to explore the effect of a firm’s scope of activities in the laser industry on its survival. To this purpose, a new variable is constructed that counts, for each year of its presence in the industry, the number of submarkets (in terms of laser types) that a firm was active in.¹⁴ As noted above, some of the listings of submarket activities refer to sales rather than production activities. Accordingly, the number of submarkets provides a broad measure of a firm’s presence in the laser industry, but cannot be used to evaluate the breadth of its laser manufacturing capabilities. The submarket variable is included in the specification of Model 5. Its coefficient estimate is negative, sizable, and significant at the .01 level, and indicates that firms with a broader presence in the laser industry were more likely to remain active laser producers. The log-likelihood of the estimation increases substantially over that of Model 4. Accounting for the scope of activities of laser firms affects the coefficient estimates of the other variables in quite different ways. The estimates for diversifiers/“parent” spin-offs as well as for serial entrepreneurs are almost unaffected, suggesting that the above-average performance of these entrants cannot be explained by a disproportionate scope of their activities. In contrast, the coefficient estimate of the dummy variable denoting integrating distributors is reduced by a third of its absolute value, and it is no longer significant. These firms are typically active (as distributors) across a broad spectrum of submarkets, which apparently is an important factor contributing to their performance. Finally, it is noteworthy that when the submarket variable is included in the model specification, the coefficient estimate of firm age is increased substantially and becomes significant at the .05 level. There is a tendency of firms to enter more submarkets over time. However, the statistical results suggest that those firms that do *not* broaden their scope of activities are increasingly likely to exit from the laser industry.¹⁵

¹³ Due to small group size and censoring of most observations, the group of “parent spin-offs” cannot meaningfully be analyzed separately.

¹⁴ Alternatively, an aggregate measure of the experience a firm accumulated in the different submarkets was experimented with. It produced results very similar to the ones obtained with the simpler measure.

¹⁵ All model specifications reported in this section are proportional models assuming that the age-dependent part of the exit hazard is independent of firm characteristics. To test the validity of this assumption, Models 1-5 were

7. Results III: determinants of spin-off entry

The large number and strong performance of spin-offs in the German laser industry suggest that this group of entrants warrants further study. The present section will therefore probe into the characteristics of incumbent firms that influenced the formation of spin-offs. Of the 48 spin-off entrants in the German laser industry, five had foreign parent firms, and one firm founder refused to disclose his former employer. Accordingly, there are 42 spin-offs originating from (identifiable) German laser firms. Following the methodology adopted by Klepper and Sleeper (2005), a series of different analyses is performed to identify the factors affecting the likelihood that an incumbent firm spawned any spin-offs, the likelihood that it spawned spin-offs initially producing a particular type of laser, and the timing of spin-off generation, respectively. In all analyses, the ordered logit methodology is adopted to account for the presence of multiple positive outcomes. Moreover, all analyses are performed alternatively for the formation of all 42 spin-offs and for that of the 22 “involuntary” or “entrepreneurial” spin-offs with (identifiable) German parent firms.

The first ordered logit (reported as Model 6a in Table 2) analyzes the likelihood that any spin-offs emerged from a given firm over the entire time period from its entry into the laser industry through 2003 (postmortem spin-offs are thus allowed for). The total number of years the firm was active in the laser industry is included as a performance measure.¹⁶ Based on the theoretical considerations on employee learning discussed in section 3 above, longer-lived firms are expected to have more spin-offs. In addition, a dummy variable *Acquired* denotes firms that exited through acquisition (by a competitor). As acquisitions are often accompanied by changes in management and career prospects, more spin-offs are expected in acquired firms. Finally, two dummy variables denoting diversifiers and *Allspins*, respectively, are included in Model 6a to investigate whether spin-offs are more likely to be created in parent firms with specific backgrounds. An identical specification is also used to analyze the formation of “entrepreneurial” spin-offs (narrowly defined). Results of this analysis are reported as Model 6b in Table 3.

re(-)estimated using the full Gompertz specification, which allows γ to vary with the covariates. Doing so did not improve the explanatory power of the models relative to the proportional specifications (based on likelihood ratio tests). The coefficient estimates for the age-dependent terms were all insignificant.

¹⁶ Two important firms (Lambda Physik and Laser-Optronic) were acquired by foreign competitors, yet remained active and at least partially autonomous laser producers for a number of additional years. They also had several spin-offs. Experience and longevity measures for these firms include post-acquisition years up to their eventual exit/integration into the parent firm.

The empirical results are consistent with the theoretical predictions. In both Models, 6a and 6b, coefficient estimates for the performance variable and the *Acquired* dummy are positive and significant (in Model 6a, both at the .01 level; in Model 6b, at the .01 and .05 levels, respectively), suggesting that longer-lived and acquired firms were more likely to be parents of spin-offs.¹⁷ Coefficient estimates are moreover very similar in Models 6a and 6b. Apparently, parent firm characteristics favoring the organization of “entrepreneurial” spin-offs are similar to those favoring “parent” spin-offs and serial entrepreneurship. In contrast, no systematic differences in spin-off likelihood are found between parent firms with different backgrounds, as the coefficient estimates for both background dummies are insignificant in Models 6a and 6b.

A similar model specification is adopted to study the factors determining the likelihood that spin-offs initially producing a specific laser type emerge from a given incumbent firm. Again following the approach adopted by Klepper and Sleeper (2005), the initial laser types produced by each spin-off entrant were identified, and all incumbent firms were treated as potential parents of spin-offs entering with any one of the eight laser types. 15 spin-offs are listed with more than one laser type in their initial year. These firms are counted as separate spin-offs of their parent firm in all their initial laser types.¹⁸ The explanatory variables included in the analysis are identical to Models 6a and 6b, except for an additional variable counting the total number of years a firm was active in each of the submarkets defined by laser types, which provides a measure of submarket-specific firm performance.

Results for this specification are reported as Models 7a (Table 2) and 7b (Table 3) for the broad and narrow spin-off definitions, respectively. Coefficient estimates for the new variable measuring submarket performance are positive and significant (at the .01 level) in both models. The effect of the general performance measure on spin-off generation is reduced by more than 50 % relative to Models 6a and 6b, and its coefficient estimates are no longer significant. This finding suggests that spin-offs are primarily enabled by narrow, submarket-specific capabilities of their parent firms (which are reflected by the latter’s longevity in that submarket) rather than by more general capabilities (which are reflected by the parent firm’s survival in the laser industry). The coefficient estimates of the acquisition dummy variable are

¹⁷ There is a seemingly trivial explanation for the effect of longevity: in longer-lived firms, there is more time for spin-offs to be organized. Note, however, that since all potential parent firms are in the sample through 2003, early entrants rather than long-lived firms should have benefited from this trivial effect of time.

¹⁸ This approach departs from the methodology of Klepper and Sleeper (2005). It was chosen because the primary interest of the analysis was to find the factors accounting for spin-offs of a specific type. Moreover, qualitative evidence suggests that the respective spin-offs did indeed enter with several initial laser types. There are several reasons for this. For example, some spin-offs focusing on diode-pumped solid-state lasers were listed as both semiconductor and solid-state laser producers. Other spin-off entrants specialized on specific laser uses (such as specific medical applications) and produced more than a single type of laser for these applications.

substantially reduced relative to Models 6a and 6b, but they remain significant at the .05 levels in both estimates. Similar to the earlier analyses, no background-specific effects on spin-off formation are found for either diversifiers or the *Allspin* group.

Finally, another set of ordered logits is estimated to analyze the entry times of laser spin-offs as well as the determinants of initial laser types. To this purpose, the number of spin-offs is recorded separately for each firm, year, and initial laser type. Models 8a and 8b use a similar set of explanatory variables to Models 7a and 7b. In addition to the variables measuring general and submarket-specific performance and the dummy denoting acquired firms, two new dummy variables, *Exit_plusmin2* and *Increase_Sub*, are included in the specification. *Exit_plusmin2* assumes the value 1 in the five-year period around the exit years of failing and acquired firms, and is 0 in all other years. (It is 0 in all years for firms surviving through 2003.) *Exit_plusmin2* picks up spin-offs generated in the time period surrounding the exit of a potential parent firm, either by acquisition or for different reasons. If the positive effect of the acquisition dummy in the earlier models is indeed due to the (expected) acquisition event, rather than, for example, peculiar characteristics of firms that are eventually acquired, then *Exit_plusmin2* is expected to eliminate the effect of the *Acquired* variable. *Increase_Sub* assumes the value 1 if a firm's current number of submarkets exceeds the number of submarkets in which the firm was active two years before.¹⁹ This variable is included as a proxy of a firm's capacity or willingness to exploit its technological knowledge. Based on the theoretical considerations in section 3, a widening scope of activities in the potential parent firm should lower the number of spin-offs created by its employees, and the coefficient estimates for *Increase_Sub* are therefore predicted to be negative. Because of their failure to help explain spin-off formation in the earlier models, the dummy variables denoting diversifiers and *Allspins* are dropped from the specification.

Results of the ordered logit estimation of this specification are reported as Models 8a (Table 2) and 8b (Table 3). Compared to Models 7a and 7b, the coefficient estimates for the performance measures are substantially reduced. Qualitatively, parent firm performance in the submarket of the spin-off's initial laser remains significant at the .01 level, whereas the general performance measure remains insignificant in both models. *Exit_plusmin2* has a positive, large, and highly significant coefficient estimate. Its effect on the coefficient estimate of *Acquired* differs subtly between the analyses for the broader and the narrower spin-off definition. While losing significance in both models, *Acquired* is reduced by almost 90 % in Model 8a, whereas it only decreases by 40 % and remains sizable in Model 8b. This

¹⁹ *IncreaseSub* is 0 in the year of entry and after the firm's exit. In the first post-entry year, it assumes 1 if the number of submarkets presently served is larger than in the entry year.

difference may be an indication that, as regards the formation of “entrepreneurial” spin-offs, acquired firms are different already before the time of their acquisition. Contrary to expectations, the coefficient estimate of *Increase_Sub* is positive but not significant in Model 8a. It switches sign (but remains insignificant) when the analysis is restricted to the narrow group of “entrepreneurial” spin-offs in Model 8b, indicating that any positive relationship between the expansion of parent firm activities and the likelihood of spin-off formation is limited to “parent” spin-offs and serial entrepreneurial activities. Even for the “entrepreneurial” spin-offs, however, no systematic trade-off is found between parent firm expansion (as measured by the proxy variable, which is unable to pick up new products launched within the same class of laser media) and spin-off activities.

The use of annual observations enables the construction of measures for the current experience of laser firms, both in terms of general laser industry experience and experience with specific laser types. In the final specification, the performance measures based on a firm’s total years in the laser industry and in the specific submarkets are therefore replaced by variables counting the number of years that a firm has been active in the industry or the relevant submarket *at the time of spin-off formation*. These new variables are interpreted as proxies of the organizational experience that employees of incumbent firms can draw upon at any given time. In contrast, since they do not take into account the parent firm’s longevity beyond the time of spin-off formation, they are no measures of parent firm quality. It is expected that more spin-offs are created in firms with more industry and submarket experience. To account for decreasing returns to further experience beyond a certain point, the measures of industry and submarket experience are included both linearly and squared in the analysis. In addition, the *Acquired*, *Exit_plusmin2*, and *Increase_Sub* dummy variables are included. Finally, two additional dummy variables denote parent firms that were active in the laser industry or the relevant submarket, respectively, in the year of spin-off formation.

Similar to the performance measures used in earlier model specifications, only submarket experience - but not general industry experience - is found to affect the likelihood of spin-off formation in any given year. The coefficient for the linear measure of submarket experience is positive, sizeable, and significant (at the .01 level) in both Models 9a and 9b. The quadratic term is negative and significant (also at the .01 level), indicating diminishing marginal effects of additional submarket experience. The coefficient estimate of the dummy variable denoting firms that are currently active in the relevant submarket is positive and significant (at the .05 level), whereas that denoting current laser producers is implausibly negative but insignificant in both Models 9a and 9b. This finding indicates that recent

experience matters in the spin-off process, and further adds to the evidence that spin-off founders use specific rather than general experience gained on the job. The coefficient estimates for *Acquired*, *Exit_plusmin2*, and *Increase_Sub* are very similar to those in Models 8a and 8b.

8. Discussion

The first objective of the present study was to study whether, and to what extent, patterns of industry evolution are driven by industry-specific factors, which should be reflected in similar evolutionary patterns across nations. As a consequence, the study was deliberately designed such that the results for the German laser industry could be compared to existing findings on the U.S. laser industry. Strong evidence for international regularities in industry evolution was found in this comparative endeavor. The distinctive features characterizing the evolution of the U.S. laser industry were reproduced for its German counterpart. In Germany as well as in the U.S., no shakeout occurred in the number of producers, but there was sustained entry into the industry decades after its inception. Moreover, no evidence was found for first-mover advantages of earlier entrants, and increasing firm age did not reduce exit hazards in either country. All these results run counter to the stylized facts of the industry life cycle. Their similarity in both countries indicates that the technological factors noted above – heterogeneity of product submarkets, and the continual discovery of new applications for lasers – indeed underlie the particularities characterizing the evolution of the laser industry. At the same time, they provide support to the general thrust of the work on industry evolution, which predominantly concentrates on technological determinants rather than, for example, institutional factors.

Pre-entry backgrounds and performance of entrants into the German laser industry likewise were similar to those of U.S. laser firms. In Germany as well as in the U.S., a substantial fraction of entrants was organized by scientists working in universities or public research organizations. In the German laser industry, these academic startups performed significantly worse than all other groups of entrants. This is an intriguing finding, particularly in light of the emphasis and support that German policy makers have recently given to academic startups. On a more positive note, laser firm spin-offs figured prominently among the entrants into the German industry. They accounted for a large share of entrants – even if the most restrictive spin-off definition is adopted, the share of spin-off entrants in Germany is

at least equal to that in the U.S. laser industry. This result shows that spin-offs are not a U.S.-specific phenomenon, even though there is little explicit recognition of spin-offs in either the scholarly work on entrepreneurship or in policy debates in Germany. Consequently, the potential normative issues surrounding spin-offs, for example as regards their appropriation of knowledge created in the parent firm and their impact on the parent firm's future performance, are also relevant outside the U.S.

The finer distinctions between different types of entrants provided further insight into the role of spin-offs into the German laser industry. While as a group, spin-offs were among the most successful entrants, there appear to be pronounced within-group differences in performance. Only the firms started by serial laser entrepreneurs, but not the spin-offs started by "ordinary" employees, performed significantly better in the survival analysis than the control group consisting of academic firms and (other) startups. This result is consistent with findings in other industries, suggesting that the prior position of spin-off founders affects their ability to accumulate valuable knowledge. Clearly, serial entrepreneurs are in a strategic position to acquire knowledge and transfer it to their new ventures. The available data do not allow, however, to test whether performance differences among the other spin-offs can also be explained by the prior positions of their founders.

Analysis of the spin-off process provided substantial evidence that spin-offs tap into the knowledge base of their parent firms. More spin-offs are started by employees of better performing firms, presumably because there is more to learn in these firms. In addition, the likelihood of spin-off formation increases with the accumulated experience of the parent firm – again, this is consistent with the interpretation that employees of more experienced firms are able to absorb more valuable knowledge. Both performance and experience effects are narrowly restricted to the relevant submarkets, suggesting that the knowledge transfer between parent firm and spin-off is limited to rather specialized knowledge. The likelihood of spin-offs was moreover found to be strongly increasing at the time of exit or acquisition of the parent firm. This lends support to the conjectured role of triggering events in the spin-off process, both in the case of serial entrepreneurship (either because bankruptcy of the existing firm may induce the start of a new one, or because selling the existing firm provides funds to start a new one) and in the case of spin-offs started by ordinary employees, who face changed opportunity costs of starting a firm when their current employer leaves the laser business or is acquired by a competitor.

A general implication of the observed performance effects of pre-entry experience is that technological capabilities were of limited importance as determinants of firm success in

the German laser industry. The academic startups should have been equally well endowed with this kind of knowledge as the spin-offs, yet they performed less well. It would also seem that principals of distribution firms, being remote from the R&D and the manufacturing process of the producers whose lasers they sold, were less able to absorb technological knowledge than academics or spin-off founders. Nonetheless, when integrating into laser manufacturing, these firms were among the top performers. A limited role of technological capabilities is moreover consistent with Sleeper's (1998) finding that in the U.S. laser industry, spin-offs started by individuals with technical experience performed less well than spin-offs whose founders had a sales or marketing background. This relative unimportance of technological capabilities may be specific to the laser industry, however. In part, it may be explicable by the fact that most founders of laser firms have gone through a science or engineering education, with many of them holding Ph.D.'s. Firm founders thus seem to differ little in their academic credentials, yet spin-off founders or principals of integrating distribution firms possess *additional* experience that distinguishes them from entrepreneurs with a purely academic background. Furthermore, technological capabilities may play a more important role in industries where products are less differentiated and production is more large-scale than in the laser industry.

Differences in knowledge about market opportunities and customer needs accumulated prior to entering the industry appears the most straightforward explanation for the observed performance differences. It is consistent with the finding that spin-offs draw on specific knowledge and enter submarkets where their parent firms have experience. It is moreover plausible to assume that employees of incumbent firms learn about market opportunities that (for whatever reasons) the incumbent firm does not pursue. Similarly, distributor firms are almost by definition in close contact with customers and are therefore likely to learn about their needs and the corresponding opportunities. In contrast, knowledge about markets and customer needs is presumably what academic startups lack most.

The parallels found in the evolution of the U.S. and the German laser industries also indicate that the presence of international competition did not fundamentally alter the evolutionary dynamics. In particular, it did not preclude domestic entry into the industry. The total number of entrants in Germany is about 30 % that in the U.S. laser industry. Moreover, the difference between the two countries is most pronounced as regards diversifiers. It therefore appears that substantial opportunities for entrepreneurial entry opened up in the German laser industry – and that German entrepreneurs were able and willing to exploit them. However, international competition did affect the evolution of the German laser industry in

more subtle ways, which have not been explored in the existing work on industry evolution. Foreign laser producers were instrumental for the organization and entry of a substantial number of German producers. A few German firms (including two early ones) were organized as spin-offs of foreign laser producers. Import and distribution of lasers also proved to be a viable channel of entry into laser production, with the respective group of entrants being highly successful on average. On the exit side of the industry, U.S. competitors acquired a number of German firms, including some of the most prominent ones. These patterns suggest that both firm entry and acquisition are relevant channels of international knowledge transfer in the evolution of industry that are worthy of further scholarly attention.

Finally, the evolutionary patterns observed in the empirical analysis point to underlying determinants and processes, but they can neither prove the role of the suggested factors nor their relevance outside the laser industry. Klepper and Thompson (2005) conclude their study on submarkets in the U.S. laser industry by underlining the need for investigating empirical irregularities in industry evolution. Further study of the particular features of laser technology and laser markets will be helpful to better understand the driving forces underlying the divergent evolutionary dynamics of the laser industry. However, to establish that the features thus identified are indeed causing the observed departures from the regular patterns of industry evolution, the *regularities within the irregularities* have to be explored. Comparative studies across national industries, along the lines of the present paper as well as a small set of other studies referred to above, is one way to achieve this, but not the only one possible. Even more promising appears a two-dimensional comparative approach, which analyzes a selected set of industries differing in well-defined ways, taking a sample of countries for each industry. This kind of approach would clearly require access to very rich data. However, given the growing number of empirical work on industry evolution, it seems to become increasingly feasible.

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Table 1: Survival of German laser producers, 1964-2003 (Gompertz specification)

	Model 1	Model 2	Model 3	Model 4	Model 5
Cohort 2	.227 (.519)				
Cohort 3	-.012 (.978)				
Academic Startups		.840** (.011)			
Diversifiers			-.684** (.045)		
Allspins			-.982*** (.007)		
Divs. / parent spin-offs				-.949*** (.006)	-.984*** (.005)
Serial entrepreneurs				-1.560** (.038)	-1.520** (.043)
Entrepreneurial spin-offs				-.610 (.143)	-.479 (.252)
Integrating Distributors				-1.565** (.039)	-1.075 (.158)
Number of Submarkets					-.405*** (.007)
Constant	-3.244*** (.000)	-3.364*** (.000)	-2.591*** (.000)	-2.505*** (.000)	-1.988*** (.000)
Age	.013 (.611)	.021 (.352)	.018 (.437)	.028 (.225)	.051** (.029)
No. of obs. (firms/failures)	1070 (143/50)	1070 (143/50)	1070 (143/50)	1070 (143/50)	1070 (143/50)
Log-likelihood (P > chi ²)	-126.678 (.718)	-124.172 (.017)	-123.222 (.023)	-121.439 (.025)	-116.932 (.001)

Note: p-values in parentheses; *** $p \leq .01$; ** $p \leq .05$; * $p \leq .10$

Table 2: Determinants of annual spin-off generation by German laser firms, 1964-2003 (ordered logits, ancillary parameters not reported)

All spin-offs

	Model 6a	Model 7a	Model 8a	Model 9a
Dependent variable	All spin-offs	All spin-offs (by laser type)	Spin-offs by year (by laser type)	Spin-offs by year (by laser type)
Total years (industry)	.134*** (.000)	.038 (.117)	.016 (.390)	
Total years (laser type)		.117*** (.000)	.080*** (.000)	
Prior years (industry)				-.024 (.690)
Prior years ² (industry)				.002 (.333)
Prior years (laser type)				.320*** (.000)
Prior years ² (laser type)				-.012*** (.000)
Diversifier	-.974 (.156)	-.021 (.957)		
Allspins	-.299 (.596)	-.313 (.426)		
Active firm (industry)				-.490 (.211)
Active firm (laser type)				1.036** (.011)
Acquired	1.674*** (.003)	.761** (.042)	.089 (.764)	.114 (.688)
Exit_plusmin2			1.364*** (.000)	1.198*** (.000)
Increase_Sub			.404 (.238)	.513 (.158)
No. of obs	142	1136	13664	13664
Log-likelihood (P > chi ²)	-79.570 (.000)	-206.256 (.000)	-381.718 (.000)	-361.439 (.000)
Pseudo R ²	.146	.157	.074	.123

Note: p-values in parentheses; *** p≤.01; **p≤.05; *p≤.10

Table 3: Determinants of annual spin-off generation by German laser firms, 1964-2003 (ordered logits, ancillary parameters not reported)

Entrepreneurial spin-offs

	Model 6b	Model 7b	Model 8b	Model 9b
Dependent variable	All spin-offs	All spin-offs (by laser type)	Spin-offs by year (by laser type)	Spin-offs by year (by laser type)
Total years (industry)	.126*** (.000)	.048 (.101)	.018 (.502)	
Total years (laser type)		.097*** (.002)	.075*** (.004)	
Prior years (industry)				.033 (.714)
Prior years ² (industry)				-.000 (.925)
Prior years (laser type)				.377*** (.001)
Prior years ² (laser type)				-.019*** (.006)
Diversifier	-.113 (.894)	.671 (.240)		
Allspins	-.253 (.747)	.298 (.612)		
Active firm (industry)				-.604 (.272)
Active firm (laser type)				1.185** (.045)
Acquired	1.667** (.012)	.946** (.039)	.559 (.154)	.588 (.115)
Exit_plusmin2			1.235*** (.001)	1.010*** (.007)
Increase_Sub			-.371 (.546)	-.329 (.605)
No. of obs	142	1136	13664	13664
Log-likelihood (P > chi ²)	-49.245 (.000)	-124.718 (.000)	-219.140 (.000)	-208.283 (.000)
Pseudo R ²	.190	.162	.073	.119

Note: p-values in parentheses; *** p≤.01; **p≤.05; *p≤.10

Figure 1: Active firms, entrants, and exiters in the German laser industry

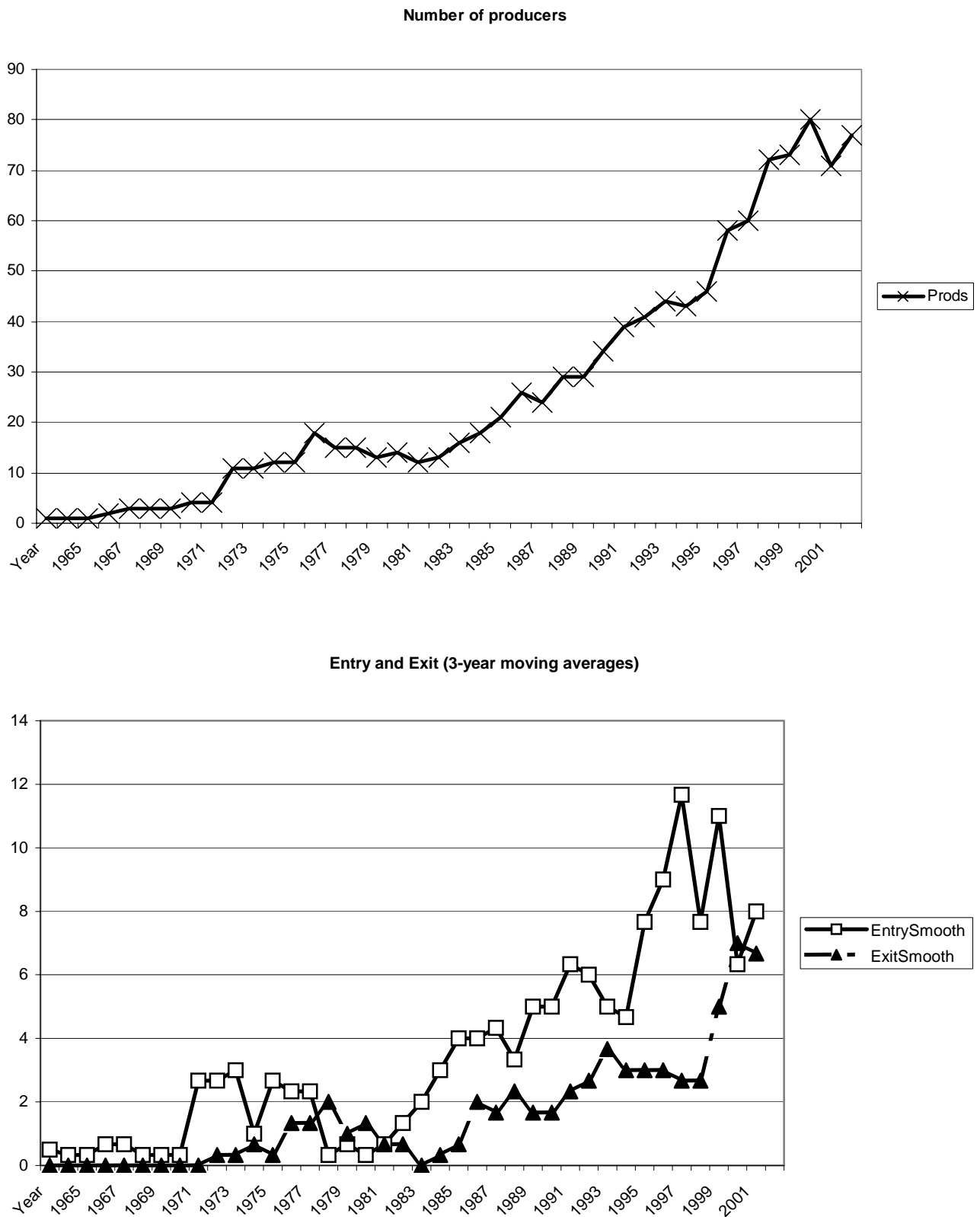


Figure 2: Active firms in German laser industry by background

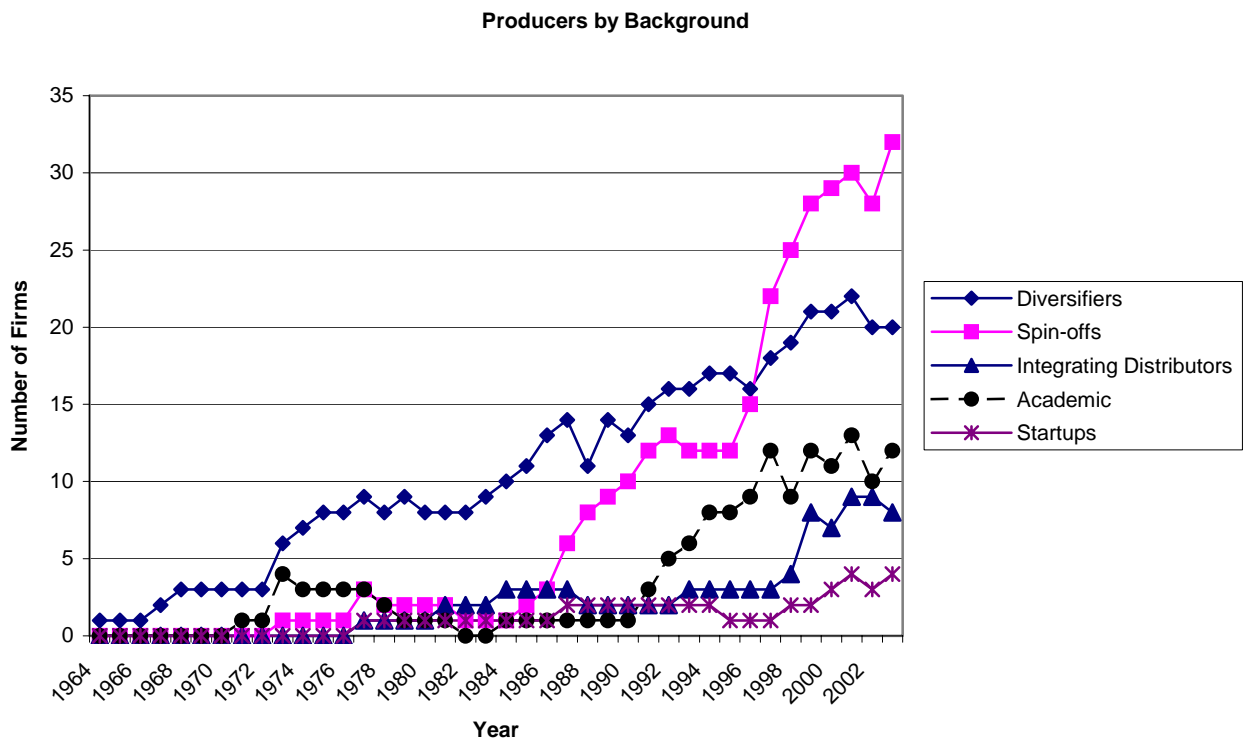


Figure 3: Active firms in German laser industry by laser type

